DETERMINATION OF EXPLOSION PARAMETERS OF LPG-AIR MIXTURES IN THE CLOSED VESSEL

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ABSTRACT

The experimental results of the measurements of the explosion pressure and rate of explosion pressure rise as a function of propane/butane concentration in the mixture with air in the 20 L explosion chamber are tested. The research was aimed at determination of the explosion pressure and limits. The influence of initial temperature of the mixture (changing in the range of 293–473 K) on the fundamental explosion parameters was also investigated. The ignition source was an induction electrical spark. It was stated, that the increase of initial temperature of the LPG-air mixture causes a significant increase of the explosion range. From the experimental result, the concentration of LPG and air mixture just explodes at the range 2% to 10% of LPG in air. The concentration of LPG at 4% gives the highest value of explosion pressure which at this condition, an explosion of LPG becomes very dangerous. The highest of deflagration index for LPG is 29. So, the designing of LPG tank storage should have value of deflagration index more than 29 to resist the over pressure from happen. The change of concentration of the LPG-air mixture causes a significant effect to maximum explosion pressure and maximum rate pressure rise. But it not means that the more concentration of LPG in air will increase the explosion pressure.

ABSTRAK

Daripada hasil eksperimen bagi menentukan tekanan letupan dan kadar kenaikan tekanan letupan sebagai fungsi bagi kepekatan propana dan butana dalam udara di dalam Gas fire explosion. Objektif kajian ini adalah untuk menentukan nilai tekanan letupan dan juga had letupan bagi LPG. Kesan Suhu awal campuran turut dikaji kesannya kepada parameter letupan. Sumber nyalaan adalah daripada induksi percikan elektrik. Semakin bertambah suhu awal LPG dalam udara akan mengakibatkan pertambahan mendadak kepada julat had letupan. Daripada hasil eksperimen, kepekatan LPG dalam udara hanya akan meletup pada julat 2% hingga 10% LPG dalam udara. Pada kepekatan 4% LPG dalam udara akan menghasilkan nilai tekanan letupan yang paling tinggi yang mana pada keadaan ini, letupan LPG adalah sangat merbahaya. Nilai deflagration index yang paling tinggi bagi LPG ialah 29. Oleh sebab itu, dalam pembinaan tangki LPG, tekanan yang lebih tinggi daripada nilai indekx deflagrasi perlulah diambil kira untuk menampung jika berlaku lebihan tekanan. Perubahan kepekatan LPG dalam udara akan menyebabkan kesan yang ketara pada tekanan letupan maksimum dan kadar kenaikan tekanan letupan maksimum. Tetapi ini tidak bermakna lebih besar kepekatan LPG dalam udara akan menyebabkan kenaikan tekanan letupan.

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K_{max}	-	Deflagration Index
V	-	Volume of Vessel
P_{max}	-	Maximum Explosion Pressure
$(dp/dt)_{max}$	-	Maximum rate pressure rise
LPG	-	Liquefied Petroleum Gas
LEL	-	Lower Explosion Limit
UEL	-	Upper Explosion Limit
U		Burning Velocity
C		Speed of Sound
D		Detonation Velocity
t		Time

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Liquefied Petroleum gas (LPG) has become more popular compared to other liquid fuels based on a few factors i.e. easy to handle, less pollution, minimum space and can produce a high quality product [1]. There are a few concepts of liquefied petroleum gas distribution to the customer and it depends on the categories of customer such as whether it is domestic, commercial and industry. Liquefied petroleum gas will be delivered to the customer either using cylinder bulk storage or pipeline.

Liquefied petroleum gas or commercially known as LPG is a group of hydrocarbons derived from crude petroleum processes or natural gas, which are gases at normal temperatures and atmospheric pressures but which become liquid with either a moderate drop in temperature or pressure, or both. With that characteristic sometimes LPG is known as a 'hydrocarbon borderline product'. Liquefied petroleum gas is a mixture of petroleum hydrocarbons consisting mainly of propane and butane and it can also exist in its individual components such as pure propane or butane [1]. Besides the main components, other minor components, which may exist in LPG, are propylene, butylenes, and butadiene with these minor components mainly depending on its sources. The difference in the LPG produced in crude petroleum processes is that some of the unsaturated hydrocarbon appears together with the LPG such as propylene and butylenes. Statistically, in the market, 75 percent of LPG is derived from natural gas and 25 percent is from crude

petroleum processes. In Malaysia, however, the differential among the two cannot be identified because of the bottling plant design in such a way that the product from the gas processing plant and the refinery come with a commingle line.

An understanding of the behavior of LPG is necessary to assist in the planning and engineering design of process plant, transportation and storage, safety and other applications. LPG can be easily liquefied and vaporized. Propane is liquefied when it is frozen below - 42 ^{o}C under atmospheric pressure or pressurized at above 7 bar (700 kPa) under constant temperature. Butane is more easily liquefied under the conditions of –0.5 ^{o}C and 2 bar (200 kPa). Furthermore, as LPG becomes extremely less voluminous (propane reduced to one over 270, butane one over 240) when liquefied, it is feasible to be safely transported and stored. LPG has a high evaporation heat point, requiring a large quantity of evaporation heat when vaporized. So, installation of separate vaporization facilities is required when a large quantity of LPG is used such as for industrial purpose.

LPG is colorless, odorless and tasteless in liquid and vapor form, yet liquid leaks are often characterized by foggy conditions at ground level as the cooling effect condenses water vapor in the air, and frost may occur at the point of escape. Only a small quantity of odorant is added in order to detect it when leaking. A liquid, LPG is only half of the weight of water yet in gaseous form is twice as heavy as air, so it is difficult to disperse and tends to hug the ground, sliding downhill to accumulate in lower lying areas. It is propane and butane that is the most commonly used and most easily liquefied of these gases. Both have flammability limits between 2 – 4 percent in air, so just 1 liter of split liquid cloud create up to 12.5 m3 of flammable vapor which could be ignited perhaps 50m downwind from the leak point. It is observed that the flammability range of LPG becomes narrow with addition of nitrogen gas. The information of this limit is very much required for prevention of explosive hazards. However, the degree of hazards depend on many factor such as the mass of substances released, physicochemical properties of the substance in the moment of its release, flammability and toxicity of the medium flowing out. Even though LPG is not poison but after expose to LPG it will cause death due to be asphyxia from hypoxia as a result of the exclusion of oxygen by the gas.

Commercial LPG in the market normally consists of propane and butane with 30 percent and 70 percent in composition respectively. However, its composition will vary accordingly and subject to the application, country and surrounding temperatures. Generally, the gas industry will follow the agreement with clients or follow the specification fixed by the Gas Processor Supplier Association (GPSA) about the composition. The specification of GPSA is based on the maximum vapor pressure, minimum vaporization rate and the limitation of the components that will cause corrosion such as water and sulfur. This means that the industry will use both of the cases. However, usually LPG contains certain amount of residue with higher vaporization points falling in the range of lubricant oil. The sources of residue are the LPG processing equipment i.e. pumps, compressors and containers. In industries, there is a routine need to analyze residues in LPG for quality control. Usually, on specific application, residues concentration of LPG must meet industrial codes. For instance, the Australia LPG Association requires the residue concentration below 20 ppm of mass.

1.2 Problem Statement

The problems occur when to design the LPG tank. In this process, the important parameter must be determined to ensure the tank is in safe. LPG kept in the tank has a high pressure. The tank must have special characteristics to hold LPG from explode when exposed to the spark or fire.

When we analyse an internal explosion, we will find that the gas cloud size is the main parameter determining pressure build-up. The geometrical conditions nearly always support flame acceleration and pressure build-up. So, if a large cloud is formed within equipment it is likely that there will be a severe explosion if it ignites. Confined gas explosions are explosions within tanks, process equipment, pipes, in culverts, sewage systems, closed rooms and in underground installations. Confined explosions are also called internal explosions.

An internal explosion may result in loss of containment. The subsequent event can then be strong blast waves from high pressure reservoirs, fires or toxic releases. In the chemical and hydrocarbon process industries, we will find a large variety of cases where internal gas explosions may occur. Such explosions can be caused by uncontrolled leaks, or simply by accidental purging with air (and thereby formation of fuel-air mixtures). There is limited information available in the open literature about these aspects of gas explosions. It is beyond the scope of this chapter to present detailed methods for analysis gas explosions in such systems.

The availability of an explosion model is able to predict accurately and quickly the explosion pressures produced by an ignition of gases or vapors in confined spaces would be great use to many companies and organizations. Obvious areas of application are in the design of enclosures, vessels, etc. to minimize and contain the effects of explosions; in the selection and design of explosion protection measures, for example explosion vents and flame arresters and in undertaking hazard assessments of installations. Two specific examples of the use of an explosion model, which illustrate the potential benefits, are flameproof enclosures and explosion venting.

All flameproof equipment has to be tested and certified that it meets the current standard. Part of the testing involves hydraulic testing of the flameproof enclosure, the hydraulic test pressure being based on the explosion pressures measured in the enclosure. A model capable of predicting the explosion pressures could be used to optimize the layout of the internal components to give the lowest explosion pressure, resulting in an enclosure of lower mechanical strength being required and a consequent saving in cost. In the longer term, the use of such a model might also lead to a reduction in the experimental testing required and thus a saving in the cost of certification.

1.3 Objective

The objective of this study is to find the value of maximum rates of pressure rise and then determine the deflagration index, $K_{G.}$ The research will attempt to overcome the hazard of LPG explosion in the closed vessel

1.4 Scope

The study will focus on how to determine the deflagration index of LPG at the different concentration. This experiment will run at the range of 1% to 10% concentration of LPG mix in the air. It can be easy to determine the range of explosion limit because it is still the same with flammability limit of LPG.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Liquefied petroleum gases (LPG) are substances such as propane and butane, which are transported and stored in the liquid phase in tanks under sufficiently high pressure. It is generated as a by-product either of oil and gas production or refining. At normal temperatures and pressures, but which turn liquid at moderate pressures; its main constituent is propane, and it is sometimes referred to by that name. The composition components of LPG are much simpler than that of gasoline. LPG is thought to be a cleaner fuel because it is has less impact on air quality.

Varieties of LPG bought and sold include mixes that are primarily propane, mixes that are primarily butane, and the more common, mixes including both propane (30%) and butane (70%), depending on the season—in winter more propane, in summer more butane. Commercial LPG marketed in this country (30% propane and 70% butane) exerts a vapor pressure of approximately 700 kPa (100 psig).Propylene and butylenes are usually also present in small concentration. A powerful odorant, ethanethiol, is added so that leaks can be detected easily.

Explosions in LPG-air gaseous mixtures in confined spaces are a well-recognized hazard, due to the high pressure and high rate of pressure rise reached quickly after ignition by a local energy source. Such processes may damage a vessel without a proper venting or explosion-suppressing device. The cause is the fast delivery of the combustion heat that cannot be compensated by the slow heat

dissipation through conduction, convection or radiation, before contact of the flame front with the walls.

Knowledge of the fundamental explosion parameters of gas-air mixtures, like maximum explosion pressure, maximum rate of explosion pressure rise, lower and upper explosion limits plays a significant role in formulating safe working conditions for various industrial installations.

The knowledge of the appropriate values of the main explosion parameters is necessary, because various explosion research centers have published data, which often differ significantly from each other, for instance. Results of experiments depend on many different parameters of the investigated process, such as energy and type of ignition source, size and shape of explosion chamber, initial temperature and pressure of the flammable mixture. Distributions of the obtained results of the measured explosion parameters also depend upon conditions of carrying out the research. For this reason, the details of the apparatus parameters and research procedures used in the investigations should be taken into consideration.

2.2 Typical Characteristics of Commercial LPG

LPG is odorless but a stench agent is added to assist in its detection in case of leakage. The odorant used in LPG is ethyl mercaptan, which possesses a distinctive and unpleasant odor. Ethyl mercaptan is selected because it is non-corrosive, has low sulphur content and possesses a boiling point very near that of LPG.

LPG is colorless whether in liquid or vapor form. The white cloud, which appears around a LPG leakage point, is not the product itself but chilled water vapor condensed from the surrounding air by the evaporating liquid or cooled vapors.

At ambient temperatures, LPG is highly volatile and flammable. Its vapor forms flammable and explosive mixtures with air. The vapor is heavier than air and can travel along the ground, into drains and conduits to a possible distant ignition source and can flash back explosively.

LPG consists almost entirely of carbon and hydrogen with negligible amounts of sulphur and other impurities. For practical purposes, therefore, stoichiometric air requirements and waste gas volumes can be determined by assuming complete combustion of the carbon and hydrogen contents.

LPG is a high performance fuel, but will only ignite if mixed with a quantity of air in roughly a gas:air ratio of between 1:50 and 1:10 (lower than the limits for mains gas). This low limit of flammability means that even small leaks could have serious results.

LPG is chemically reactive and will cause natural rubber and some plastics to deteriorate. Only equipment and fittings specifically designed for LPG should be used. **Table 2.1** shows the physical and chemical properties of LPG from the Shell Company. The safety data sheet for LPG is shows in the **appendix B1**.

Table 2.1: Physical and chemical properties of LPG (Shell Company)

LPG	**Properties**
Form	Gas. May be liquefied by pressurization
Color	Colorless
Odor	Very faint petroleum odor 22,000 to 36,000 mg/m^3
Specific gravity	0.5 @ 20ºC
Vapor density	1.55 (air = 1)
Vapor Pressure at ambient	500 kPa
Boiling point	-40^{o}C to 80 ^{o}C (-40 to 176^{o}F)
Freezing point	-190^{o}C (-310^{o}F) (propane)
Coefficient of water/oil	2.36 [log P]

Flash point	-104°C (-156°F)
Auto ignition	450°C (842°F)
Lower flammable limit	1.8% -1.9%
Upper flammable limit	9.5%
Hydrocarbon Composition (by Volume)	
Commercial Propane (C_3H_8)	30%
Commercial Butane (C_4H_{10})	70%
Total Sulphur (stenched)	< 75 mg/kg
Free Water (Visual Inspection)	none
Relative density (compared to dry air)	1.85
Copper Corrosion Strip	1
Calorific Value, gross	49.5 MJ/kg 21,300 Btu/lb
Calorific Value, nett	45.7 MJ/kg 19,600 Btu/lb

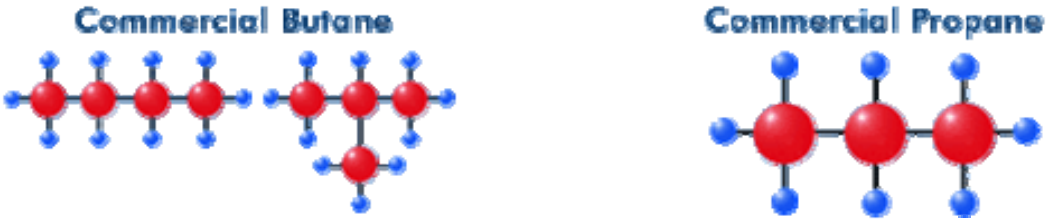

Figure 2.1: Structure of commercial butane and commercial propane

Figure 2.1 shows the structure of commercial butane and commercial propane in tree dimension. The chemical composition of propane is C_3H_8 and butane, C_4H_{10}. Because the make-up of each gas contains traces of other gases, there may be small variances in the exact composition. The terms commercial propane and commercial butane are often used to describe LPG of acceptable quality for most applications.

The characteristics of propane and butane are different. it can be describe easily by its chemical properties. **Table 2.2** shows the physical and chemical properties propane. **Table 2.3** shows the physical and chemical properties butane.

Table 2.2: Physical and chemical properties propane

Appearances	Colorless liquefied gas
Odor	Odorless, odorant added to provide a distinctive smell
Boiling Point	-42^{o}C
Flash Point	-104 ^{o}C
Flammability Limits	2% to 11% in air
Auto flammability	460-580 ^{o}C
Vapor Pressure	7.5 bar at 15 ^{o}C
Specific Gravity of Liquid	0.512 at 15 ^{o}C (Water = 1.0)
Specific Gravity of Vapor	1.5 at 15 ^{o}C (Air = 1.0)
Solubility in Water	Insoluble

Table 2.3: Physical and chemical properties butane

Appearances	Colorless liquefied gas
Odor	Odorless, odorant added to provide a distinctive smell
Boiling Point	-2^{o}C
Flash Point	-60 ^{o}C
Flammability Limits	2% to 9% in air
Auto flammability	410-550 ^{o}C
Vapor Pressure	2 bar at 15 ^{o}C
Specific Gravity of Liquid	0.575 at 15 ^{o}C (Water = 1.0)
Specific Gravity of Vapor	2.0 at 15 ^{o}C (Air = 1.0)
Solubility in Water	Insoluble

2.3 Explosion

An explosion is defined as an event in which energy is released over a sufficiently small period of time and in a sufficiently small volume to generate a pressure wave of finite amplitude traveling away from the source. This energy may have been originally stored in the system as chemical, nuclear, electrical, or pressure

energy. However, the release is not considered to be explosive unless it rapid and concentrated enough to produce a pressure wave that can be heard [2].

Gas explosions can occur inside process equipment or pipes, in buildings or off-shore modules, in open process areas or in unconfined areas. When we are talking about a gas explosion as an event, it is a more general term. It is then common to include the events both before and after the gas explosion process, see the diagram below.

Figure 2.2 shows what can happen if combustible gas or evaporating liquid is accidentally released into the atmosphere. If the gas cloud, formed from the release, is not within the flammability limits or if the ignition source is lacking, the gas cloud may be diluted and disappear. Ignition may occur immediately, or may be delayed by up to tens of minutes, all depending on the circumstances. In case of an immediate ignition (before mixing with air or oxidizer has occurred) a fire will occur.

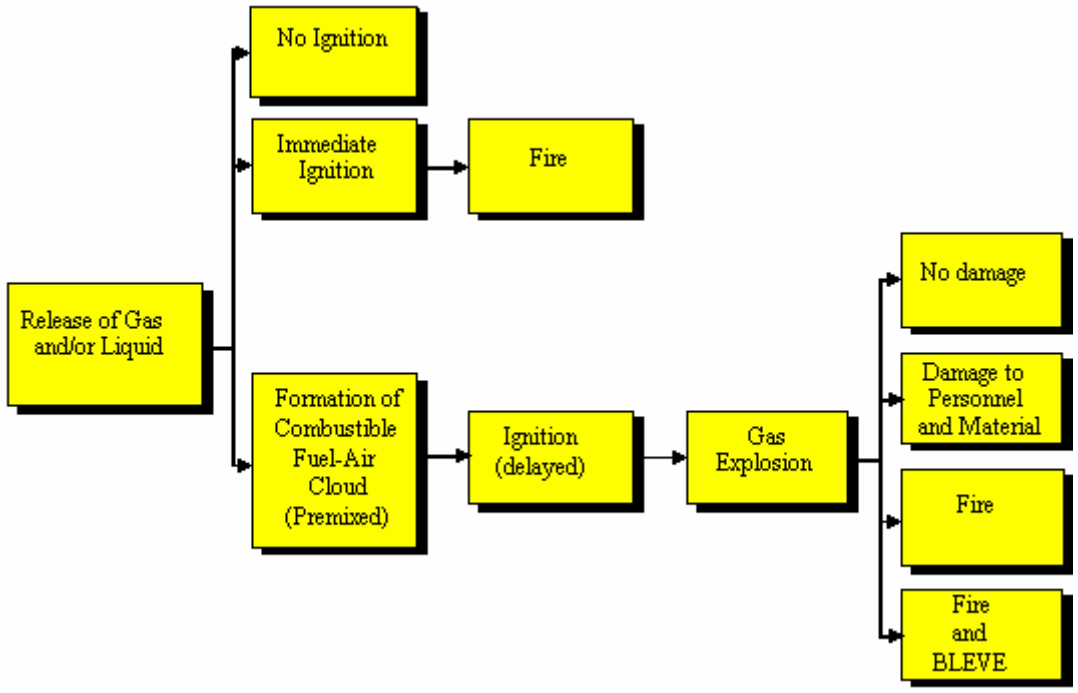

Figure 2.2: An event tree showing typical consequences of accidental releases of combustible gas or evaporating liquid into the atmosphere [3]

The most dangerous situation will occur if a large combustible premixed fuel-air cloud is formed and ignites. The time from release start to ignition can be from a few seconds up to tens of minutes. The amount of fuel can be from a few kilograms up to several tons.

The pressure generated by the combustion wave will depend on how fast the flame propagates and how the pressure can expand away from the gas cloud (governed by confinement). The consequences of gas explosions range from no damage to total destruction. The pressure build-up due to the gas explosion can damage personnel and material or it can lead to accidents such as fires and bleve's. Fires are very common events after gas explosions. When a cloud is ignited the flame can propagate in two different modes through the flammable parts of the cloud. These modes are deflagration and detonation

The deflagration mode of flame propagation is the most common. A deflagration propagates at subsonic speed relative to the unburned gas, typical flame speeds (relative to a stationary observer) are from the order of 1 to 1000 m/s. The explosion pressure may reach values of several barg, depending on the flame speed.

A detonation wave is a supersonic (relative to the speed of sound in the unburned gas ahead of the wave) combustion wave. The shock wave and the combustion wave are in this case coupled. In a fuel-air cloud a detonation wave will propagate at a velocity of 1500-2000 m/s and the peak pressure is typically 15 to 20 bar.

An explosion results from ignition of a combustible material (dust, gas or mist) when mixed with oxygen present in the air. When this takes place inside a process or storage enclosure, the rapid rise in pressure developed will exert destructive forces within a few milliseconds that will place both personnel and equipment at risk. Most materials handling, processing and storage equipment is not designed to resist the pressure of a deflagration. Only equipment designed to resist the maximum pressure (P_{max}) developed by the combustion process will survive,